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SIMULATED EFFECTS OF NUTRIENT ENRICHMENT BY CANADA GEESE ON MACROPHYTES AND ALGAE IN OHIO LAKES

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ABSTRACT

We tested the hypothesis that phosphorus enrichment in lakes by goose droppings can enhance growth of algae and macrophytes at goose densities at or above those occurring in nature. Seasonal changes in Canada goose populations were determined on five northeastern Ohio lakes to estimate the amount of nutrients added as goose droppings. Numbers of geese were highest during winter migration, but some resident geese remained year-round. In a laboratory experiment, effects of various goose densities (0–2.6 x 10^5 geese/ha) were simulated by adding different amounts of droppings weekly to 1-L bottles containing lake water, algae and *Ceratophyllum demersum*. After four weeks, dissolved total phosphorus concentrations in bottles receiving 1 dropping/week (~6000 μg P/L) was higher than in bottles with other treatments (16–75 μg P/L). Phytoplankton chlorophyll *a* levels and periphyton biomass were highest in the 1 dropping/week treatment. *Ceratophyllum demersum* biomass increased by 4.5 g/plant in the 0.1 dropping/week treatment, but plants senesced in 1 dropping/week treatment. We calculated how much phosphorus was added in goose droppings and how much was taken up by *Ceratophyllum demersum* and periphyton biomass in each treatment, and we estimated that plants took up most of the available phosphorus in 0, 0.0001, and 0.001 droppings/week treatments. However, there was a surplus of phosphorus in 0.01, 0.1, and 1 droppings/week treatments, which simulated 2.6 x 10^3, 2.6 x 10^4, and 2.6 x 10^5 geese/ha, respectively. These results indicate that goose droppings can increase macrophyte growth and promote a switch from clear lakes dominated by macrophytes to turbid lakes dominated by algae, but this will probably only occur at goose densities (26,000–260,000 geese/ha) that are not likely to occur in lakes in Ohio.

Introduction

Lakes are important sources for drinking water and recreational activities such as swimming, boating, fishing, and waterfowl hunting. Although the need to develop sustainable management strategies for multiple use areas is growing, achieving this goal can be difficult. For example, contamination by toxins and algal blooms are critical issues in lakes used for drinking water, and high rates of nutrient inputs in many areas make it difficult to maintain macrophyte beds used as refugia for juvenile fish in lakes used for recreation

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(Moss et al., 1980; Brönmark and Weisner, 1992).

Interactions among nutrient levels and growth of algae and macrophytes are complex (Vollenwieder, 1968; Correll, 1998). For example, rooted macrophytes can obtain nutrients from sediments, but phytoplankton and non-rooted macrophytes compete for dissolved nutrients in the water column (Barko and James, 1998). *Ceratophyllum demersum* L. is a common non-rooted macrophyte found throughout temperate regions of the world (Sculthorpe, 1967, p. 167), and absorbs most of its nutrients with foliar uptake (Denny, 1972). This species can reduce phytoplankton abundance with shading (Goulder, 1969) and by the release of allelopathic chemicals (Nakai et al., 1999). However, high turbidity from phytoplankton or resuspension of inorganic sediments from biotic factors (*e.g.*, feeding carp) or abiotic factors (*e.g.*, wave action) will inhibit macrophyte growth and promote dominance by phytoplankton (Spence, 1982; Nagid et al., 2001; Wetzel, 2001, p. 626).

Recently, expanding populations of Canada geese (*Branta canadensis* L.) have become an important management concern in Ohio's lakes. Tens of thousands of Canada geese pass through northern Ohio (Ohio Department of Natural Resources, 2002) as they travel to and from their wintering grounds in the southern United States and breeding grounds in Canada. Since the late 1960s when Canada goose populations were at their lowest levels, populations have steadily increased throughout North America (Ankney, 1996; National Audubon Society, 2002). Historically, most Canada geese only occurred in Ohio during the migratory period (Bookhout et al., 1989). Today however, many geese spend the entire year in Ohio, and these are called "resident" geese.

Waterfowl can contribute substantial amounts of nitrogen and phosphorus to lakes and wetlands with their droppings (Manny et al., 1975; Bazely and Jefferies, 1985; Gere and Andrikovics, 1992; Marion et al., 1994; Manny et al., 1994; Mitchell and Wass, 1995; Moore et al., 1998). Canada geese graze on aquatic and terrestrial vegetation and are often found in urban areas. Geese release an average of 28 droppings per day (Manny et al., 1975), and droppings are a source of nitrogen and phosphorus in lentic habitats (Manny et al., 1994; Moore et al., 1998; Kitchell et al., 1999). Therefore, large populations of Canada geese have the potential to contribute significant amounts of nutrients to lakes (Conover and Chasko, 1985; Ankney, 1996). However, the limnological impact of increasing populations of geese in lakes in Ohio is not clear.

In this study, five lakes in northeast Ohio were surveyed to determine seasonal changes in populations of Canada geese, and goose densities were used to estimate the amount of nutrients hypothetically added by geese to one of these lakes (East Twin Lake). Laboratory experiments were used to test the hypothesis that phosphorus enrichment by goose droppings could enhance growth of periphyton, phytoplankton, and *Ceratophyllum demersum*, and we examined if this would occur at goose densities occurring in nature.

Methods

Study site description

All surveyed lakes (East and West Twin Lakes, Lake Hodgson, Lake Pippen, and Lake Rockwell) are located in northeastern Ohio (Portage Co.). East and West Twin Lakes are 4 km north of the city of Kent. The watershed of the Twin Lakes is mostly residential, and the shorelines are largely mowed lawns (Cooke et al., 1977). Both lakes are used for recreational purposes, including swimming, fishing, and boating (Cooke et al., 1977). Lakes Hodgson, Pippen, and Rockwell are surrounded by deciduous and coniferous woodland with scattered residential homes. Lake Hodgson is about 5 km east of Kent and is a drinking water reservoir for the city of Ravenna. Lakes Pippen and Rockwell are about 4 km northeast of Kent. Both are drinking water reservoirs for the city of Akron. Morphological and hydrological data of the study lakes are listed in Table 1.

Goose population survey

Seasonal changes in Canada goose numbers on East and West Twin Lakes, Lake Hodgson, Lake Pippen, and Lake Rockwell were determined by counting the number of geese using each lake once every 2–4 weeks from February to October 1999. Surveys were conducted with binoculars at each survey site (20–30 minutes per site) between 12:00 and 17:00. All geese that were swimming on the lake, and grazing, sleeping, or loafing near the edges of the lake were counted. Few geese were observed flying during the survey, and therefore individual geese were probably not counted on more than one lake during a survey.

Nutrient addition experiment

In 2001, a laboratory experiment was used to determine the growth response of *C. demersum* and algae across a wide range of goose densities. East Twin Lake was chosen as the model lake because extensive limnological and ecological work has been conducted there in the past (Cooke et al., 1977; Fleischmann, 1999; Lombardo, 2002). On 17 June 2001, *C. demersum* plants and fresh goose droppings were collected at East Twin Lake. Droppings were stored frozen until used in the experiment. Plants that were approximately 15–20 cm in length were chosen for the experiment, and all macroinvertebrates were removed. Plants were blotted with a paper towel for 10 seconds and their initial wet weight was measured. Wide–mouth Nalgene, bottles (1-L) were filled with filtered (212 µm mesh) East Twin Lake water, and one plant was randomly assigned to each bottle. Periphyton density was sampled by suspending one glass microscope slide

Table 1. Physical characteristics of the five lakes surveyed in 1999.

	East Twin Lake[1]	West Twin Lake[1]	Lake Hodgson[2]	Lake Pippin[3]	Lake Rockwell[3]
Latitude	41°12´N	41°12´N	41°08´N	41°11´N	41°11´N
Longitude	81°20´W	81°21´W	81°17´W	81°19´W	81°20´W
Watershed area (ha)	334.5 (both Twin Lakes)		376.5	410	53,612.8
Altitude above sea level (m)	318	319	330	321	321
Lake surface area (ha)	26.9	34.0	77.5	49.0	250.9
Maximum depth (m)	12.0	11.5	20.7	23.7	9.1
Mean depth (m)	5.0	4.3	7.8	11.9	3.1
Volume (m^3)	13.5×10^5	15.0×10^5	n/a	2.7×10^6	7.6×10^6
Water renewal time (years)	0.54	1.49	n/a	1.0	0.05

[1] Cooke, 1977
[2] Olive, 1961
[3] K. Coy, Akron City Water Supply, personal communication

on the side of the container with dental floss. Periphyton were allowed to colonize the slides during a two-week conditioning period. Any macroinvertebrates that were observed in the bottles during this period were removed.

Physical characteristics of some goose droppings were determined. Droppings were thawed and wet weight was measured. Dry weight was measured after drying the droppings at 105° C for 24 hours. Moisture content of droppings was calculated by subtracting dry weight from wet weight. Ash free dry weight (AFDW) was determined after droppings were ignited in a muffle furnace at 550° C for 60 minutes. Organic content was determined by subtracting AFDW from dry weight. Total phosphorus content (TP) of individual droppings was estimated by multiplying dropping dry weight by 1.5 percent as described in Manny et al. (1994).

After the two-week conditioning period, six goose dropping treatments were established: 1) control: no goose droppings added; 2) 0.0001 droppings added/week; 3) 0.001 droppings added/week; 4) 0.01 droppings added/week; 5) 0.1 droppings added/week; and 6) 1 dropping added/week. We calculated the number of droppings (X) that would be deposited daily to East Twin Lake (volume = 13.5×10^8 L) to get the equivalent concentration for each treatment as:

$$X = [(\text{no. of droppings per L}) * 13.5 \times 10^8] / 7$$

Manny et al. (1975) estimated that one Canada goose releases an average of 28 droppings per day, and we calculated the number of geese (Y) that would produce the number of droppings deposited daily to East Twin Lake for each treatment as:

$$Y = X / 28$$

These calculations show that our treatments simulated the expected amount of droppings added to East Twin by approximately: 0; 69; 690; 69,000; 690,000; and 6,900,000 geese, respectively. Furthermore, given that the surface area of East Twin Lake is 26.9 ha, our treatments were equivalent to approximately: 0; 26; 2.6×10^2; 2.6×10^3; 2.6×10^4; and 2.6×10^5 geese/ha (Table 2).

A slurry of goose droppings was made fresh each day it was needed by mixing 10 randomly selecting droppings with 1 L of distilled water. Dilutions of slurry that corresponded to different goose dropping treatments were added once weekly; controls received an equal volume of distilled water each week. Each treatment was replicated five times (30 bottles total), and the experiment ran for four weeks. All bottles were held in an environmental chamber at 15° C with a 14 h light/10 h dark cycle, and light levels were 22–28 microeinsteins/m^2/sec at 400–700 nm. Distilled water was added to each bottle every 4–7 days to compensate for losses from evaporation.

At the end of the two-week conditioning period and at the end of the four week experiment, we sampled the water column by slowly pipetting 20 ml of water from each bottle without disturbing any solid debris (e.g. undissolved droppings, senescent plants) in the container. Water column TP was measured using standard methods (Clesceri et al., 1998, p. 6-139). Phosphorus content of solid debris was not measured. At the end of the experiment, periphyton biomass on the microscope slides was measured, and phytoplankton response was determined by measuring chlorophyll *a* concentrations in the water column using standard methods (Clesceri et al., 1998, p. 10-18). Final wet weight of each *C. demersum* was measured after blotting the plant for 10 seconds on a paper towel. Mean change in *C. demersum* biomass was determined by subtracting initial wet weight from final wet weight.

Phosphorus uptake by *C. demersum* and periphyton was estimated to determine whether their growth was limited by the amount of phosphorus available in the different treatments. Available phosphorus was calculated by adding TP measured in the water column at the end of the conditioning period to TP added in droppings over the four week experiment. Periphyton biomass in each container was estimated by calculating the amount of periphyton expected to occur on the

Table 2. Effects of geese at East Twin Lake simulated in the nutrient addition experiment.

			Simulated conditions [3]		
Treatment [1]	TP added (µg) [2]	Geese	Geese/m^3	Geese/ha	TP/lake (kg)
0	0	0	0	0	0
0.0001	11.04	6.9×10^2	5.2×10^{-4}	26	14.9
0.001	1.104×10^2	6.9×10^3	5.2×10^{-3}	2.6×10^2	1.49×10^2
0.01	1.104×10^3	6.9×10^4	5.2×10^{-2}	2.6×10^3	1.49×10^3
0.1	1.104×10^4	6.9×10^5	5.2×10^{-1}	2.6×10^4	1.49×10^4
1	1.104×10^5	6.9×10^6	5.2	2.6×10^5	1.49×10^5

[1] Number of droppings added per week to 1-L bottles

[2] Amount of TP added as droppings over the four-week experiment

[3] Number of geese (Geese), number of geese per m^3 of water (Geese/m^3), number of geese per ha (Geese/ha), and TP added over four weeks (TP/lake) at East Twin Lake simulated by each treatment

inside of the 1-L bottle (surface area: 0.055 m^2) given the mean periphyton density measured on microscope slides at end of the experiment for each treatment. Published uptake rates (McCormick et al., 2001) for periphyton (1000 µg TP/g periphyton dry weight/day) were used to estimate phosphorus uptake by periphyton over the four week experiment. Lombardo (2002, p. 125-134) reported that uptake rates for *C. demersum* ranged from 1.7–3.2 µg TP/g plant wet weight/day. Because *C. demersum* biomass increased during the four week experiment, expected phosphorus uptake was estimated for initial and final *C. demersum* biomass with both low (1.7 µg TP/g plant wet weight/day) and high (3.2 µg TP/g plant wet weight/day) uptake rates. The range of total phosphorus uptake in the bottles was calculated by adding periphyton uptake to the minimum *C. demersum* uptake (initial biomass; low uptake rate) and the maximum *C. demersum* uptake (final biomass; high uptake rate). We calculated this using the average initial and final biomass over all treatments. We could not estimate phosphorus uptake by phytoplankton because we did not directly measure their biomass, therefore our estimated uptake rates are somewhat conservative.

Statistical analyses

Data were analyzed using SigmaStat Version 2.0 (SPSS Inc. Headquarters, Chicago, Illinois) with an alpha error set at 0.05 for all analyses. Data were first tested for normality and equal variance and were $\log_{10}(x+1)$ transformed when necessary. Data collected at the end of the conditioning period and at the end of the experiment were analyzed separately. Total phosphorus, chlorophyll *a*, *C. demersum* biomass, and periphyton biomass means were compared among goose dropping treatments with one–way ANOVAs followed by Tukey's post-hoc test when significant differences were detected.

Results

Canada goose populations

Goose populations on most lakes were highest during the migration period in February–March and declined to lower levels during April–October when resident geese remained in the area (Figure 1). Goose populations were an order of magnitude higher during the migration period (mean geese/lake = 136) than during the rest of the year (mean geese/lake = 11). The Twin Lakes and Lake Rockwell had the highest goose populations in February–March (400–500 geese), but numbers in all lakes were < 70 geese in the summer and fall. Physical characteristics and estimated phosphorus content of goose droppings collected at East Twin Lake are presented in Table 3.

Nutrient addition experiment

Initial Total Phosphorus (TP) in the water column was not significantly different among treatments ($P > 0.05$) and ranged from 43–80 µg P/L (Table 4). Final TP was not different among treatments ($F = 90.11$, $P < 0.001$) except that levels in the 1 dropping/week treatment (5984 µg P/L) were significantly higher than all other treatments which ranged from 16–75 µg P/L (Table 4).

Initial *C. demersum* biomass ranged from 3–5 g/plant (Figure 2) and was not significantly different among treatments ($P > 0.05$). *Ceratophyllum demersum* grew well in all treatments, except many plants senesced in the highest treatment (1 dropping/week) by the end of the experiment. There were no significant differences in final *C. demersum* biomass among treatments ($P > 0.05$). However, there was a general pattern that biomass increased slightly from 0 to 0.1 droppings/week treatments and then sharply declined at 1 dropping/week, as plants died off (Figure 2). Change of *C. demersum* biomass was different among treatments ($F = 5.885$, $P < 0.002$). During the four week experiment, biomass of *C. demersum* decreased 1.4 g/plant in the 1 dropping/week treatment, which was different than in the 0.1 dropping/week treatment where biomass increased 4.5 g/plant. Changes in *C. demersum* biomass were not significantly different among any other treatments.

Periphyton biomass was higher in the 1 dropping/week treatment than all other treatments ($F = 4.898$, $P < 0.005$)

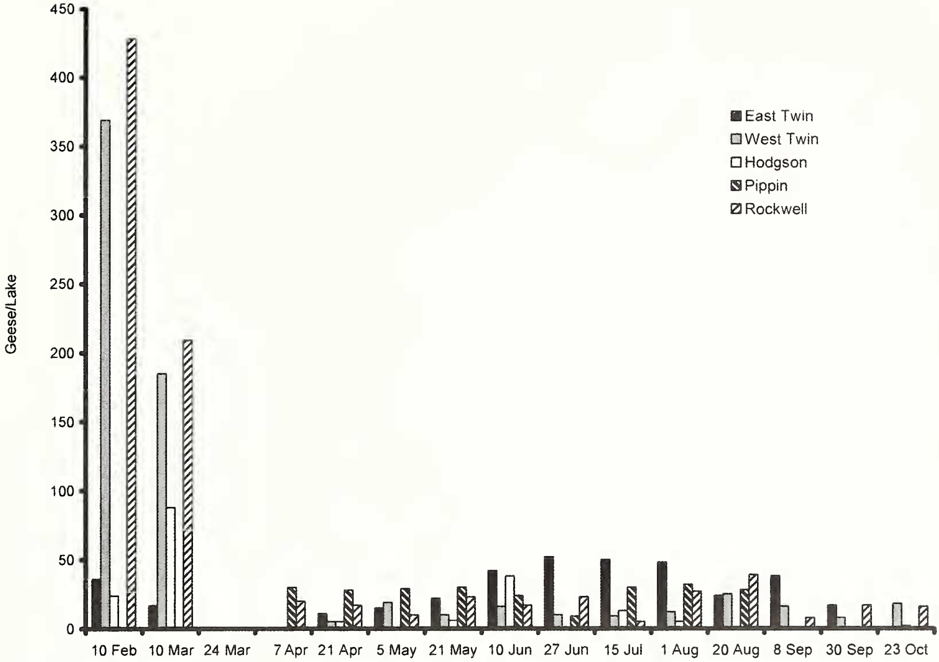

Figure 1. Canada goose populations on five northeast Ohio lakes in 1999.

(Figure 2), and chlorophyll *a* levels were higher in the 1 dropping/week treatment than the 0.0001 dropping/week treatment (F = 11.716, $P < 0.001$) (Figure 2). The water in the control treatment bottles was almost clear. Water in the 1 dropping/week treatment bottles was turbid with a dark yellowish-brown color, and the surface was covered with debris from droppings and dead *C. demersum*. Water in the 0–0.1 dropping/week treatment bottles was light yellow with almost no floating debris.

Table 5 reports the amount of phosphorus that we estimated was available in the bottles, and the amount of phosphorus taken up by *C. demersum* plants and periphyton in each treatment. Estimated total phosphorus uptake by periphyton and *C. demersum* was above available TP in the 0, 0.0001, and 0.001 droppings/week treatments, but there was a surplus of TP in the 0.01, 0.1, and 1 droppings/week treatments.

Discussion

This research demonstrates that geese can affect periphyton, phytoplankton, and macrophytes in lakes through the addition of nutrients in their droppings. *Ceratophyllum demersum* and algae grew slowly in control treatments that had little available phosphorus. There was an insignificant trend of higher growth with increasing phosphorus added in droppings. The highest *C. demersum* and algae growth were found in the 0.01 and 1 dropping/week treatments, respectively. These treatments also had the most surplus phosphorus. Much of the phosphorus not taken up by plant growth remained in the bottles as debris from undissolved droppings, especially in the 1 dropping/week treatment bottles. Therefore, additional phosphorus would become available if this material decomposed. These data suggest that growth of *C. demersum* and periphyton at the 0–0.001 droppings/week treatments were limited by available phosphorus levels, but more phosphorus was added at higher treatment levels than could be taken up by *C. demersum* and algae.

Shallow lakes tend to be either turbid with abundant phytoplankton or clear with abundant macrophytes (Scheffer et al., 1993). Habitats that are extremely eutrophic (> 1000 μg P/L) such as wastewater treatment plants are generally dominated by

Table 3. Mean (± one standard error) physical characteristics of one goose dropping.

	N [1]	Mean ± SE
Wet weight (g)	72	11.9 ± 0.9
Dry weight (g)	72	1.8 ± 0.1
Ash free dry weight (g)	24	1.07 ± 0.1
Percent moisture content	72	84.5 ± 1.8
Organic content (g)	24	0.70 ± 0.08
P content (g)[2]	72	0.0276 ± 0.002

[1] Indicates the number of droppings used to determine the measurement

[2] Estimated from data presented in Manny et al. (1994)

Table 4. Mean (± one standard error) total phosphorus (TP) concentrations (µg P/L) measured in the water column of 1-L bottles of nutrient addition experiment. Each treatment was replicated five times.

Treatment[1]	Initial TP[2] Mean ± SE (N=5)	Final TP[3] Mean ± SE (N=5)
0	47.21 ± 6.52	16.11 ± 1.78 **a**
0.0001	56.50 ± 7.40	42.11 ± 9.35 **a**
0.001	70.43 ± 15.01	34.51 ± 9.26 **a**
0.01	43.34 ± 5.39	38.83 ± 8.30 **a**
0.1	50.31 ± 4.24	74.78 ± 12.38 **a**
1	79.72 ± 12.75	5983.90 ± 295.85 **b**

[1] Treatments are the number of droppings added per week.

[2] TP at the end of the conditioning period

[3] TP at the end of the experiment. Values with different letters are significantly different.

phytoplankton comprised mostly of cyanobacteria (Jeppesen et al., 1994). Because phytoplankton get their nutrients from the water column, algal biomass is low under low nutrient conditions (Moeller et al., 1988). Therefore, oligotrophic lakes with low nutrient levels (< 10 µg P/L) are usually dominated by macrophytes that obtain nutrients from sediments (Scheffer et al., 1993). Lakes can exist in either state at intermediate nutrient levels (Balls et al., 1989; Beklioglu and Moss, 1996), but Irvine et al. (1989) suggested that once phytoplankton are dominant, macrophytes can be permanently suppressed due to light attenuation. In the nutrient addition experiment, algae were most abundant at concentrations of ~6000 µg P/L (i.e., the final TP in 1 dropping/week treatment), but the highest growth of *C. demersum* occurred at 75 µg P/L (i.e., the final TP in 0.1 dropping/week treatment). Therefore, the switch from a macrophyte to an algae dominated system occurred between the 0.1 and the 1.0 dropping/week treatments, which corresponds to densities of 26,000–260,000 geese/ha.

Several factors may have caused the dramatic decline of *C. demersum* at the 1 dropping/week treatment. For example, decreased light on *C. demersum* leaves caused by phytoplankton or periphyton and elevated concentrations of toxic

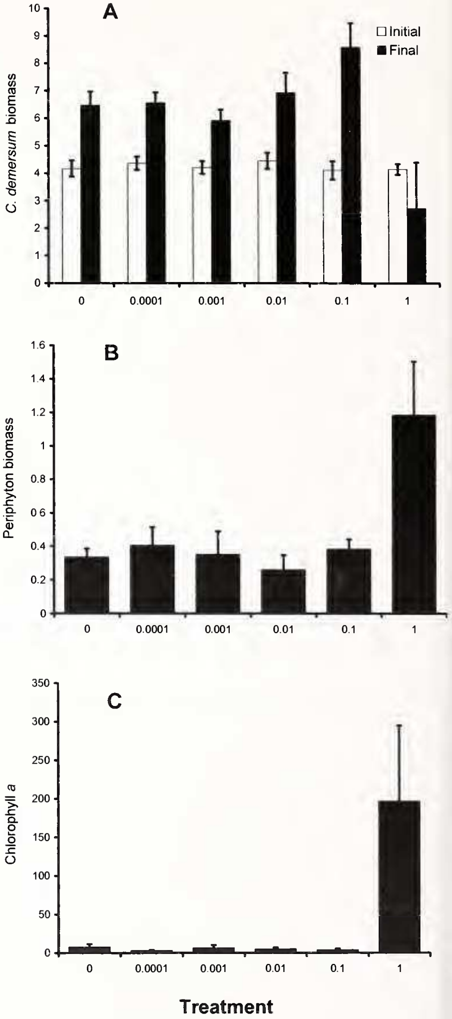

Figure 2. Amounts of *C. demersum*, periphyton, and chlorophyll *a* in the nutrient addition experiment. Treatment indicates the number of droppings added per week. A, mean (± one standard error) wet weight (g) of *C. demersum* at end of conditioning period (initial) and at end of experiment (final). B, final mean (± one standard error) periphyton biomass (g/m^2) collected on microscope slides. C, final mean (± one standard error) chlorophyll *a* concentration (µg Chl *a*/L) in the water column.

Table 5. Estimated phosphorus (µg) available and taken up by *C. demersum* and periphyton in the four-week nutrient addition experiment.

Treatment [1]	**TP available** [2]	***C. demersum*** [3]				**Periphyton** [4]	**Total uptake** [5]	
		Initial		**Final**				
		low	**high**	**low**	**high**		**minimum**	**maximum**
0	47.21	198.40	373.45	307.71	579.23	18.47	216.87	597.70
0.0001	67.54	207.54	390.66	312.29	587.84	22.28	229.82	610.12
0.001	180.00	200.40	377.22	281.68	530.22	19.35	219.75	549.57
0.01	1147.00	212.01	399.08	330.03	621.23	14.37	226.38	635.59
0.1	11,090.00	195.45	367.90	408.77	769.44	21.11	216.56	790.55
1	110,480.00	197.35	371.48	129.73	244.19	65.09	262.44	309.29

[1] Number of droppings added per week

[2] Total available dissolved phosphorus (µg/L) = mean TP in water column + TP in droppings added to 5 replicates of each treatment during the 4 week experiment

[3] *C. demersum* uptake estimated using initial and final mean plant biomass and low (1.7 µg TP/g plant wet weight/day) and high (3.2 µg TP/g plant wet weight/day) uptake rates reported by Lombardo (2002, p. 125)

[4] Periphyton uptake rates (1000 µg TP/g periphyton dry weight/day) reported in McCormick et al. (2001)

[5] Combined uptake by *C. demersum* and periphyton. Minimum uptake estimated for initial *C. demersum* biomass and the low uptake rate. Maximum uptake estimated for final *C. demersum* biomass and the high uptake rate.

compounds from blue-green algae or decomposition of droppings could have negatively affected *C. demersum* plants. Another potential mechanism is that floating and deposited debris from droppings directly shaded the *C. demersum* plants. Shading by inorganic sediments has been shown to decrease growth of submerged macrophytes and increase algal growth (Hough et al., 1989). Moreover, high numbers of waterfowl can remove a large percent of vegetation in lakes and wetlands (Giroux and Bedard, 1987; Woolhead, 1994), which would otherwise shade out phytoplankton in the water column. Further research could examine if goose grazing, in conjunction with the addition of nutrients and debris in their droppings, can act as a suite of co-occurring factors that promote conditions leading to turbid algae-dominated lakes.

Management implications

Numbers of geese observed at the five lakes we surveyed (Figure 1) were below those we have shown to promote algal blooms or suppress macrophyte growth. For example, peak numbers of migratory geese observed at East and West Twin Lakes would have hypothetically added only ~400 g P/day. If all of their droppings were deposited in East Twin Lake, it would raise phosphorus concentrations in the lake by only 2.3 x 10^{-9} µg P/L. East Twin Lake water column concentrations measured in this study were 43–79 µg P/L, and concentrations reported by Cooke et al. (1977) were 76–94 µg P/L. Therefore, inputs from peak numbers of geese observed on these lakes would have negligible effects on lake nutrient levels. Numbers of geese were slightly higher at Lake Rockwell. However, this lake is much larger than the Twin Lakes, and therefore, expected impacts of the additional nutrients would be minimal.

Our experiments demonstrate that low to moderate goose populations probably do not add enough nutrients to promote a switch from macrophyte to algal dominance in lakes we surveyed. Although the highest treatment (1 dropping/week) caused a sharp increase in phytoplankton, goose densities (260,000 geese/ha) simulated by this treatment are unlikely to occur in Ohio. For example, peak numbers of geese observed in northern Ohio in 2001 were only 55,000 geese (Ohio Department of Natural Resources, 2002). Furthermore, the number of geese corresponding to 260,000 geese/ha could not physically fit on the surface of a lake at one time. Therefore, the goose densities simulated at the 0.1 and 1.0 droppings/week treatment are not likely to occur in lakes in Ohio. However, it is important to note that others (e.g., Kitchell et al., 1999) have reported that nutrient additions from high numbers of waterfowl can cause algal blooms in some natural aquatic habitats. The effects of nutrient addition by geese will interact with other abiotic and biotic factors such as nutrient enrichment from other sources, biotic stresses, or co-occurring changes in pH, temperature, or light levels. For example, lakes where herbivores reduce macrophyte beds may have algal blooms at lower nutrient addition levels than lakes with abundant macrophytes. Furthermore, inputs of goose droppings to lakes may not be constant over time or within a lake. For example, if 690 geese overwintered for three months on a frozen area within East Twin Lake, about 45 kg of phosphorus could accumulate from goose droppings. This amount of phosphorus may have a local impact on algae and plants after ice melt in spring.

More research is needed to fully understand how nutrients from geese affect macrophytes and algae in lakes. Microcosm experiments, like our nutrient addition experiment, do not always predict biotic responses in natural habitats because there may be scale-dependent effects of treatments (Petersen et al., 1999), and because scientists cannot test for interactions among all potential variables (Cooper and Barmuta, 1993). For example, other factors have been shown to affect whether lakes switch between macrophyte and phytoplankton dominated equilibria including: 1) invertebrate herbivory of epiphytes and phytoplankton (Timms and Moss, 1984; Brönmark and Weisner, 1992); 2) fish predation of herbivorous zooplankton (Grimm, 1989); 3) macrophyte production of alleopathic chemicals that suppress phytoplankton (Wium-Anderson et al., 1987); and 4) turbidity caused by wave action (Schiemer and Prosser, 1976; Nagid et al., 2001). However, the design of our nutrient addition experiment eliminated all of these variables, and treatment effects may have been different under other conditions (e.g., in macrophyte beds with high species diversity or at different macrophyte densities). Moreover, our experiment only tested the response of plants and algae over a relatively short period (i.e., 4 weeks). Long-term impacts of nutrient addition may be different. Future research should examine interactions of nutrient addition by geese, algal grazers, predatory fish, and wind action under natural conditions.

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